AN INVESTIGATION OF OCCUPANT INJURY IN ROLLOVER: NASS-CDS ANALYSIS OF INJURY SEVERITY AND SOURCE BY ROLLOVER ATTIBUTES

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ABSTRACT

This paper investigates the circumstances surrounding vehicle rollover and the injuries resulting from this type of vehicle crash mode. Data was extracted from the NASS CDS database for the years 1997-2000. Crash events with at least one occupant and with at least one injury of AIS 3 or higher were studied, and all injuries with an AIS value of 3 or more were examined.

The frequency of rollover events were examined by vehicle type, model year, occupant position, number of quarter turns, direction of roll, roll initiation source, roll location relative to the roadway, and extent of roof intrusion. Rollover exposed occupants were examined by distribution of MAIS, safety belt usage, extent of ejection, and proximity to the roll direction. Occupant injuries were examined by safety belt usage, body region injured, injuring contact/source, and extent of roof intrusion. Most data has been distributed by vehicle type.

Results indicate head injuries (including face and brain) account for 45% of all AIS 3+ injuries. Head injuries associated with roof contact were the most frequent injury-source combination for all vehicle types. For all AIS 3+ injuries, 57% occur at roof deformations greater than the allowable limit of the FMVSS 216 standard. For head injuries associated with the roof, 81% occur when this deformation limit is exceeded. The highest opportunity area for mitigating injuries to belted and unbelted occupants was to the head and neck. The highest opportunity area for mitigating injuries by contact/source for *belted* occupants is associated with the roof and interior surfaces. For *unbelted* occupants, exterior contacts are the predominate injury source.

INTRODUCTION

Rollover continues to be a serious highway threat. Each year in the US, about 253,000 light vehicles are involved in rollovers. The number of occupants in these vehicles is about 418,000. Of these rollover exposed occupants, 266,000 are injured or killed. About 240,000 suffer minor to moderate injuries, 17,000 survive serious to critical injuries, and 10,000 are killed. The injured occupants suffer about 931,000 injuries, about 3.5 injuries per occupant. The comprehensive cost of the injuries and fatalities in rollovers is nearly $50 billion per year. As a class, rollover crashes constitute about 2.6% of the crashes, but 33% of the injury costs.

In recent times the fleet composition has changed considerably to include higher populations of light trucks (pick-ups, vans, and sport utility vehicles). In many instances, rollover propensities may be higher in these vehicles in comparison to typical passenger cars. This paper investigates the circumstances surrounding vehicle rollover and the injuries resulting from this type of vehicle crash modes. Of particular interest is the determination of injury and/or fatality trends by vehicle type.

DATA ANALYSIS OF ROLLOVERS

For the study, data was extracted from the NASS CDS database using the SAS database query software [NHTSA 2000, SAS 2002]. Only data during the years 1997-2000 was included in this analysis. These years were chosen because of the ability to review each case individually via electronic format. Crash events with at least one occupant and with at least one injury of AIS 3 or higher were studied. However, all injuries with an AIS value of 3 or more were examined. Each injury was examined with specific interest in the magnitude, injury location, and injury source.

This data investigation has been broken down to include the effect of safety belt usage, with injury sources and magnitudes identified for both belted and un-belted occupants. Additionally, the circumstances surrounding each rollover have been examined. Specifically, the location, severity, and direction of the roll were studied, including distributions by vehicle type. The role of roof deformation has also been investigated, as it pertains to injury source.

It should be noted at this point that NASS CDS weighting factors have been applied whenever possible. This allows the cases sampled by NASS CDS to be projected to the total population. These weighting factors are applicable to general characteristics of each case. In certain instances the

weighting factors are not appropriate for particular data. Typically, individual injuries in highly complex events, such as rollover, are quite specific to that event. Also, when data is subdivided into smaller subcategories, individual cases may cause unrealistic weighting or significantly affect distributions. This may be an indication that the data has been divided too finely to have statistical significance; however, these cases can still be reviewed to provide insight to certain trends. This will be further discussed when applicable to the data being reviewed.

Analysis of Rollover Events

Following the criteria outlined previously, the NASS CDS query returned 676 cases, equating to 65,360 using the weighting factors. The distribution of these cases by vehicle type is given in Table 1. Of the 676 cases, 303 involved cars, 185 involved SUVs, 141 involved pick-up trucks, and 47 involved vans.

Table 1. 1997-2000 NASS CDS rollover cases with AIS 3+ injuries.

Vehicle Type	Count	Count %	Weighted Count	Weighted %
Car	303	44.8%	29,111	44.4%
Pick-up	141	20.9%	17,232	26.3%
SUV	185	27.4%	16,378	25.0%
Van	47	6.9%	2,909	4.3%
Totals	676	100%	65,630	100%

It is also of interest to look at vehicle exposure to gage a relative difference between vehicle types. Using data from 2000 for vehicle registrations, cars were the most prominent passenger vehicles on the road with 64%, pick-up tucks followed with 19%, SUVs made up 9%, and vans 8%. This data is shown in Table 2. The data from Tables 1 and 2 identifies certain vehicle characteristics that may be influential when looking at rollover. It should be noted that cars account for 64% of the population, but only 44% of the weighted rollover cases. Light trucks or LTVs (pick-ups, SUVs, and vans) account for 36% of the population; however, they account for 56% of the rollover cases. SUVs have the largest disparity with 9% population and 25% of the rollover cases.

Table 2. Vehicle registrations in 2000 by vehicle type.

Vehicle Type	Registrations	Percent
Cars	126,647,516	64%
Pick-ups	36,606,839	19%
SUVs	17,248,225	9%
Vans	16,313,490	8%
Total	196,816,070	100%

Since LTVs, particularly SUVs, have increased in population relative to cars over the past decade, it was of interest to look at the age of vehicle involved in these rollover events. As shown in Table 3, a majority (60%) of involved SUVs are 5 years old or less. This compares to 19% for cars, 41% for pick-ups, and 16% for vans. This is indicative of the increased exposure over that time period.

Table 3. Distribution of rollover events by vehicle type and age (model year).

Unweighted

Model Year	Car	Pick-up	SUV	Van
<1980	7	9	8	3
1981-1985	20	7	6	0
1986-1990	91	22	19	14
1991-1995	110	51	60	23
1996-2000	75	52	92	7
Total	303	141	185	47

Weighted

Model Year	Car	Pick-up	SUV	Van
<1980	305	2,539	704	87
1981-1985	1,279	409	389	
1986-1990	10,573	1,400	1,613	922
1991-1995	11,432	5,856	3,870	1431
1996-2000	5,523	7,029	9,804	469
Total	29,111	17,232	16,378	2909

Prior to 1997, NASS reported the extent of the rollover by partitioning the number of quarter-turns into five categories - 1, 2, 3, 4+ and end-over-end. After 1997, a larger number of categories have been recorded. This additional resolution is further investigated in a companion paper [Digges 2003]. For the present investigation, rollovers were divided into categories of one quarter turn; 2, 3, or 4 quarter turns; and more than 4 quarter turns. This distribution is shown in Table 4. It is further distributed by vehicle type in Table 5.

Table 4. Distribution of cases by number of quarter turns.

Number ¼ turns	Count	Count %	Weighted Count	Weighted %
1	113	17%	10,984	17%
2,3,or 4	338	50%	32,261	49%
>4	225	33%	22,386	34%
Total	676	100%	65,630	100%

Table 5. Distribution of cases by vehicles type and number of quarter turns.

Weighted (counts)

Number ¼ turns	Car	Pick-up	SUV	Van
1	3,947	2,625	3,779	633
2,3,or 4	15,476	8,133	6,970	1,682
>4	9,688	5,621	6,483	594
Total	29,111	16,378	17,232	2,909

Weighted (%)

Number ¼ turns	Car	Pick-up	SUV	Van
1	14%	16%	22%	22%
2,3,or 4	53%	50%	40%	58%
>4	33%	34%	38%	20%
Total	100%	100%	100%	100%

Table 4 indicates that 83% of the crashes involved 2 or more quarter turns. Of particular interest is that 2 or more quarter turns may expose the roof to contact with the ground and/or occupant contact to the roof. Of the weighted cases, 49% experienced 2, 3, or 4 quarter turns, and 34% experienced more than 4 quarter turns. Weighted and unweighted distributions were very similar. Cars and pick-ups had similar distribution to the overall counts, while SUVs experienced slightly more events with a single quarter turn and more than 4 quarter turns. Vans experienced the largest portion of events at 4 or less quarter turns.

Since this study was looking at injury counts, it was of interest to look at roll direction as a possible factor. The distribution by roll direction is given in Table 6. Using the case counts, rolls to the driver side accounted for 53%, while rolls toward the passenger side were 47%. However, when weighting factors were applied, there is an approximate 50-50 split in roll direction. Occupant proximity to the roll direction will be discussed later.

The initiation source of rollovers may also be indicative of certain vehicle characteristics. The initiation source for all vehicles is given in Table 7. It is further distributed by vehicle type in Table 8, using weighted values. Table 7 indicates that the ground initiates 57% of rollovers for all vehicles. That is significantly higher than fixed objects, which are the second most frequent at 13%. Table 8 indicates that LTVs experience a higher percentage of ground-induced rollovers compared to cars (68% vs. 44%), while cars have a higher percentage

Table 6. Distribution of cases by roll direction.

Leading Side	Count	Count %	Weighted Count	Weighted %
Driver	355	53%	31,997	49%
Passenger	320	47%	33,589	51%
Unknown	1	0%	45	0%
Total	676	100%	65,630	100%

Table 7. Distribution of cases by rollover initiation source.

Initiation Source	Count	Count %	Weighted Count	Weighted %
Ground	362	54%	37,709	57%
Fixed Object	75	11%	8,627	13%
Vehicle	74	11%	5,084	8%
Barrier	54	8%	2,329	4%
Turn/Fall Over	46	7%	6,340	10%
Curb	26	4%	3,666	6%
Ditch / Embank.	39	5%	1,877	3%
Total	676	100%	65,630	100%

Table 8. Weighted distribution of cases by rollover initiation and vehicle type using weighted NASS values.

Initiation Source	Car	Pick-up	SUV	Van
Ground	12,890 (44%)	12,316 (71%)	11,054 (67%)	1,449 (50%)
Fixed Object	7,003 (24%)	544 (3%)	846 (5%)	233 (8%)
Vehicle	1,366 (5%)	1,042 (6%)	2,124 (13%)	552 (19%)
Barrier	975 (3%)	559 (3%)	302 (2%)	494 (17%)
Turn/Fall Over	2,390 (8%)	2,467 (14%)	1,348 (8%)	135 (5%)
Curb	3,268 (11%)	95 (1%)	302 (2%)	0 (0%)
Ditch / Embank.	969 (3%)	51 (0%)	326 (2%)	5 (0%)
Other	251 (1%)	157 (1%)	77 (0%)	41 (1%)
Total	29,111 (100%)	17,232 (100%)	16,378 (100%)	2,909 (100%)

initiated by fixed object contacts (24% vs. 5%). The higher rate of ground induced rollovers may be indicative of the difference in vehicle dynamics and roll propensity of LTVs compared to cars. Compared to other vehicle types, vans experienced a higher percentage of roll events initiated by contact with another vehicle and contact with a barrier.

In addition to the initiation source of the rollover, it may also be of interest to investigate the location of the rollover occurrence. Tables 9 and 10 show the distribution of rollovers by location with respect to the roadway. Pick-ups follow the distribution of all vehicles. Cars (79%) have a disproportionate number of cases initiate off the roadway or in the median, while SUVs (50%) and vans (44%) experience higher than average rates on the roadway. Events occurring on the roadway are typically not associated with a tripping mechanism and coincide with ground initiated rolls. This may be another indication of differences in vehicle stability and roll propensity.

Table 9. Distribution of rollover cases by location relative to roadway.

Location	Count	Count %	Weighted Count	Weighted %
Roadside - Median	445	66%	42,372	65%
On Roadway	155	23%	15,978	24%
Shoulder Paved	48	7%	5,689	9%
Shoulder Unpaved	28	4%	1,591	2%
Total	676	100%	65,630	100%

Table 10. Weighted distribution of rollover cases by location relative to roadway and vehicle type using weighted NASS values.

Location	Car	Pick-up	SUV	Van
Roadside - Median	22,981 (79%)	11,494 (67%)	6,518 (40%)	1,379 (47%)
On Roadway	2,258 (8%)	4,263 (25%)	8,170 (50%)	1,288 (44%)
Shoulder Paved	3,427 (12%)	1,229 (7%)	968 (6%)	67 (2%)
Shoulder Unpaved	446 (2%)	246 (1%)	723 (4%)	176 (6%)
Total	29,111 (100%)	17,232 (100%)	16,378 (100%)	2,909 (100%)

The final aspect of interest is to investigate the extent of roof deformation. NASS does not directly measure roof deformation with damage values (C values); however, intrusion is measured. Also, the intruding component can be the roof. For this study, a new variable was created, called "maximum roof deformation." This variable returns the maximum intrusion deformation when the roof is coded as the intruding component. The range of values follows those of the intrusion variable. In approximately 75% (510) of the cases there was roof deformation. The distribution based on extent of deformation is given in Table 11. Weighting numbers were not used for these distributions. Upon review of each case individually, it was determined that the weighting values would inappropriately affect the distributions. The maximum roof deformation was quite specific to the particular case and could be affected by numerous events within the case.

Data from Tables 4 (roll severity) and Table 11 have been combined in Table 12 to compare roof deformation with number of quarter turns. With more than 1 quarter turn the largest percentage (30%) of vehicles experience 15 – 29 cm (5.9 – 11.4 in) of deformation. Interestingly, 45% of vehicles that experience only 1 quarter turn, also experience roof deformation. When reviewing cases individually, this deformation is most commonly attributed to a planar impact following the roll event. For example, a vehicle may begin to roll and then strike a tree. This tree impact may prevent subsequent quarter turns, but may also contribute to roof deformation and/or injury. These post-roll impacts are also discussed in the companion paper, which investigates measures of roll severity [Digges 2003]. The roll of maximum roof deformation relative to injuring contacts will be discussed later.

Table 11. Unweighted distribution of cases by maximum roof deformation.

Max Roof Deformation	Count	%
0 cm	166	25%
1 – 7 cm	59	9%
8 – 14 cm	89	13%
15 – 29 cm	187	28%
30 – 45 cm	97	14%
46 – 60 cm	35	5%
≥ 61 cm	43	6%
Total	676	100%

Table 12. Unweighted distribution of maximum roof deformation by deformation extent and roll severity.

Max Roof Deform (cm)	1 quarter turn		More than 1 quarter turn	
	Count	%	Count	%
0	62	55%	104	18%
1 – 7	9	8%	50	9%
8 – 14	7	6%	82	15%
15 – 29	16	14%	171	30%
30 – 45	8	7%	89	16%
46 – 60	2	2%	33	6%
≥ 61	9	8%	34	6%
Total	113	100%	563	100%

There are some interesting observations that can be made when looking at the data in Tables 11 and 12. The current FMVSS 216 standard regulates the strength of vehicle roofs. In this standard, the vehicle's roof must withstand a load equal to 1.5 times the vehicle's weight with a maximum allowable deflection of 127mm (5 inches). When looking at all cases (Table 11), 53% exceeded 15 cm of deformation, which is in excess of the standard. For vehicles that experienced only 1 quarter turn, 31% exceeded 15 cm of deformation. Finally, 58% of vehicles that experienced 2 or more quarter turns exceeded 15 cm of deflection. This does not control for the force under which the roofs were loaded, and is a result of dynamic loading. This indicates that real-world loading of the roof may be different than what is currently regulated.

Analysis of Occupants

When looking at the 676 cases, there were a total of 800 occupants involved that sustained an AIS 3+ injury. Applying weighting factors, this constitutes 75,576 occupants. Distribution by seating position is 74% driver, 15% right front passenger, and 11% rear seat occupants. All vehicle classes had similar distributions for occupant location with the exception of vans. The distribution in vans was 53% driver, 13% right front passenger, and 35% rear seat.

Safety belt usage significantly effects injury outcome in any crash mode. This is particularly true in rollover. Of the seriously injured or killed occupants 67% (50,634) were unbelted while the remaining 33% (24,942) were buckled.

The distribution of injury severity was investigated using the maximum AIS (MAIS) for each occupant. This distribution is shown in Table 13 for unweighted and weighted values. The weighted values indicate that 62% of the injuries are MAIS 3. This data was further investigated by vehicle type (Table 14). The distributions for cars, pick-ups, and SUVs are similar to the total population of vehicles. Vans experience more MAIS 6 cases, but fewer MAIS 4 injuries. Based on the distributions across vehicle types, there did not seem to be any significant differentiations between vehicle type and MAIS. It is important to keep a perspective on the magnitude of the particular safety topic. While distributions across vehicle types are similar, it should be noted that the total number of serious to fatal injuries for cars (35,828) is approximately double that of pick-ups (18,441) and SUVs (17,688), and nearly ten times that of vans (3,619).

Table 13. Distribution of injuries by MAIS.

Injury Severity	Count	Count %	Weighted Count	Weighted %
MAIS 3	386	48%	47,187	62%
MAIS 4	177	22%	17,256	23%
MAIS 5	175	22%	9,026	12%
MAIS 6	62	8%	2,107	3%
Total	800	100%	75,576	100%

Table 14. Weighted distribution of MAIS by vehicle type.

Injury Severity	Car	Pick-up	SUV	Van
MAIS 3	22,233 (62%)	10,840 (59%)	12,083 (68%)	2,032 (56%)
MAIS 4	9,084 (25%)	4,755 (26%)	2,749 (16%)	668 (18%)
MAIS 5	3,311 (9%)	2,523 (14%)	2,654 (15%)	539 (15%)
MAIS 6	1,201 (3%)	323 (2%)	203 (1%)	380 (11%)
Total	35,828 (100%)	18,441 (100%)	17,688 (100%)	3,619 (100%)

The distribution of occupants was broken down by safety belt usage. When looking at all vehicles, there was no significant difference in MAIS distributions by safety belt usage. This data is shown in Table 15.

Table 15. Weighted distribution of MAIS injuries by safety belt usage.

Injury Severity	Belted		Unbelted	
	Count	%	Count	%
MAIS 3	16,120	65%	31,068	61%
MAIS 4	6,569	26%	10,687	21%
MAIS 5	1,844	7%	7,182	14%
MAIS 6	409	2%	1,697	3%
Total	24,942	100%	50,634	100%

When the data was further divided by vehicle type, the NASS weighting factors began to significantly affect the distributions. Individual cases were capable of changing distributions by as much as 20%. At this point it was determined that the data should not be divided further with the use of the weighting factors. Further investigations into the injuries would consider only the raw cases. While this may limit the statistical precision, it is still useful in providing insight into the nature and causes of injuries in rollover.

It has been well reported over the years that occupant ejection is a particularly harmful event [Digges 1994, Malliaris 1987]. These cases were reviewed to look at ejection, particularly by safety belt usage. As expected a large portion (66%) of the unbelted occupants were ejected, either fully or partially. This compares to 18% for belted occupants, with the majority of those being partial ejections. This data is given in Table 16.

Table 16. Unweighted distribution of belted and unbelted occupants by ejection circumstances.

Ejection Extent	Belted		Unbelted	
	Count	%	Count	%
No Ejection	196	82%	191	34%
Complete Eject	3	1%	301	54%
Partial Ejection	34	14%	63	11%
Unknown	3	1%	3	1%
Eject. Unk. Deg	3	1%	3	1%
Total	239	100%	561	100%

This data was divided by vehicle type. Table 17 displays ejection data for belted occupants and Table 18 displays the same data for unbelted. The data for belted occupants is relatively consistent across vehicle types. Pick-ups and SUVs have a slightly higher frequency of partial ejections, but this may not be significant due to relatively few cases. For unbelted occupants, Pick-ups (75%) and SUVs (72%) have a higher incidence of ejection when compared to cars (60%) and vans (61%). LTVs overall have a higher incidence of complete ejection compared to cars.

With regard to occupant location relative to the roll event, the injured occupant was on the near-side of the roll 49% of the time, and the far-side 48%. The remaining 3% were in center seating positions. This was further divided by MAIS. No significant difference in injury distributions existed based on proximity to the roll direction.

Table 17. Unweighted distribution of ejection extent by vehicle type for *belted* occupants.

Ejection Extent	Car	Pick-up	SUV	Van
No Ejection	88 (85%)	33 (83%)	59 (77%)	16 (84%)
Complete Eject	1 (1%)	0 (0%)	1 (1%)	1 (5%)
Partial Ejection	11 (11%)	7 (18%)	14 (18%)	2 (11%)
Unknown	2 (2%)	0 (0%)	1 (1%)	0 (0%)
Eject. Unk. Deg	1 (1%)	0 (0%)	2 (3%)	0 (0%)
Total	103 (100%)	40 (100%)	77 (100%)	19 (100%)

Table 18. Unweighted distribution of ejection extent by vehicle type for *unbelted* occupants.

Ejection Extent	Car	Pick-up	SUV	Van
No Ejection	107 (40%)	30 (25%)	37 (28%)	17 (39%)
Complete Eject	116 (44%)	78 (65%)	84 (64%)	23 (52%)
Partial Ejection	40 (15%)	10 (8%)	10 (8%)	3 (7%)
Unknown	2 (1%)	1 (1%)	0 (0%)	0 (0%)
Eject. Unk. Deg	0 (0%)	1 (1%)	1 (1%)	1 (2%)
Total	265 (100%)	120 (100%)	132 (100%)	44 (100%)

The effect of roll severity on injury distribution is shown in Table 19. It was found that rollover with 1 quarter turn resulted in less severe injuries. There were 134 MAIS 3-6 injuries for this group, compared to 402 injuries for the group with 2-4 quarter turns, and 264 for the group with more than 4 quarter turns. Table 19 also indicates that MAIS 4-6 injuries occur in greater frequency as roll severity increases.

Table 19. Unweighted MAIS injury distribution for all rollover exposed occupants with MAIS 3+ injuries by number of quarter turns.

Injury Severity	1-¼ turn		2,3,4-¼ turn		>4-¼ turn	
	count	%	count	%	count	%
MAIS 3	73	54%	196	49%	117	44%
MAIS 4	20	15%	86	21%	71	27%
MAIS 5	27	20%	86	21%	62	23%
MAIS 6	14	10%	34	8%	14	5%
Total	134	100%	402	100%	264	100%

Analysis of Injuries

While understanding the vehicle and general occupant trends can help with developing countermeasures for rollover, it is most important to study and understand the injury trends and associated circumstances. In that regard, the individual injuries for all occupants were studies. Again, only AIS 3+ injuries were collected and weighting factors were not utilized. Weighting factors are typically not applied to individual injuries since they are often occupant specific. In all, 2,455 AIS 3+ injuries were identified. As expected the unbelted occupants experienced more injuries than the belted population. The 239 belted occupants sustained 564 AIS 3+ injuries (2.36 injuries per occupant), while the 561 unbelted occupant's sustained 1,891 AIS 3+ injuries (3.4 injuries per occupant). Injury distributions are shown in Table 20. They were distributed for all occupants by vehicle type as shown in Table 21. Injury distributions by severity were consistent across all vehicle types.

Table 20. Unweighted distribution of AIS 3+ injuries for belted and unbelted occupants.

Injury Severity	Belted		Unbelted	
	Count	%	Count	%
AIS 3	372	66%	1,137	60%
AIS 4	117	21%	448	24%
AIS 5	62	11%	247	13%
AIS 6	13	2%	59	3%
Total	564	100%	1,891	100%

Table 21. Unweighted distribution of AIS 3+ injuries for all occupants by vehicle type.

Injury Severity	Car	Pick-up	SUV	Van
AIS 3	707 (62%)	272 (59%)	410 (62%)	120 (61%)
AIS 4	269 (24%)	111 (24%)	142 (22%)	43 (22%)
AIS 5	120 (11%)	69 (15%)	96 (15%)	24 (12%)
AIS 6	44 (4%)	9 (2%)	9 (1%)	10 (5%)
Total	1,140 (100%)	461 (100%)	657 (100%)	197 (100%)

The next step was to break down the injuries by body region (Table 22). Head injuries (including face and brain) account for 45% of all AIS 3+ injuries. Chest injuries are the second most frequent at 22%. An interesting finding is that neck injury (often a focus in rollover testing) only accounted for 5% of AIS 3+ injuries. This was fewer injuries than the lower extremities, upper extremities, and the abdomen. When looking at belted vs. unbelted, there are some differences in injury distribution. Unbelted occupants follow a similar distribution to the total population. Percentage point-wise belted occupants had 11% fewer head injuries but 10% more arm and 4% more neck injuries. The data was also divided by vehicle type (Table 23); however, no significant difference was identified with respect to body region distributions.

Table 22. Unweighted distribution of injured body region for all cases and by safety belt usage.

Body Region	All Cases		Belted		Unbelted	
	count	%	count	%	count	%
Head	1,116	45%	208	37%	908	48%
Chest	552	22%	128	23%	424	22%
Low Ext.	193	8%	51	9%	142	8%
Up Ext.	152	6%	78	14%	74	4%
Abdomen	150	6%	34	6%	116	6%
Neck	124	5%	46	8%	78	4%
Pelvic/Hip	109	4%	11	2%	98	5%
Back	55	2%	8	1%	47	2%
Unk Reg	4	0%	0	0%	4	0%
Total	2,455	100%	564	100%	1,891	100%

Table 23. Unweighted distribution of injured body region by vehicle type.

Body Region	Car	Pick-up	SUV	Van
Head	497 (44%)	200 (43%)	324 (49%)	95 (48%)
Chest	271 (24%)	104 (23%)	129 (20%)	48 (24%)
Low Ext.	90 (8%)	39 (8%)	47 (7%)	17 (9%)
Up Ext.	56 (5%)	31 (7%)	58 (9%)	7 (4%)
Abdomen	80 (7%)	33 (7%)	27 (4%)	10 (5%)
Neck	62 (5%)	22 (5%)	36 (5%)	4 (2%)
Pelvic/Hip	59 (5%)	18 (4%)	21 (3%)	11 (6%)
Back	24 (2%)	14 (3%)	12 (2%)	5 (3%)
Unk Reg	1 (0%)	0 (0%)	3 (0%)	0 (0%)
Total	1,140 (100%)	461 (100%)	657 (100%)	197 (100%)

NASS CDS attempts to identify the source of each injury based on contact or other type of interaction. For all of these cases the injury source was identified. This is shown in Table 24 for all cases and by safety belt usage. For unbelted occupants the injuring

source is something exterior to the vehicle for 49% of the injuries. This compares to 11% for belted occupants. Belted occupants experience 34% of their injuries from interactions with the roof and 26% from general interior contacts (header rails, pillars, door interior, etc.).

Table 24. Unweighted distribution of injuring contact for all cases and by safety belt usage.

Injury Source	All Cases		Belted		Unbelted	
	#	%	#	%	#	%
Ground	811	33%	34	6%	777	41%
Exterior	104	4%	7	1%	97	5%
Oth. Vehicle	71	3%	21	4%	50	3%
Roof	525	21%	194	34%	331	18%
Interior	462	19%	150	26%	324	17%
Steering	148	6%	45	8%	103	5%
Windshield	22	1%	5	0%	22	1%
Seat	43	2%	10	2%	33	2%
Seatbelt	34	1%	34	6%	0	0%
Airbag	8	0%	8	1%	4	0%
Other	60	2%	10	4%	29	2%
Unk. Source	167	7%	46	8%	121	6%
Total	2,455	100%	564	100%	1,891	100%

Table 25. Unweighted distribution of injury contact by vehicle type for *belted* occupants.

Injury Source	Car	Pick-up	SUV	Van
Ground	7 (3%)	7 (7%)	18 (9%)	2 (5%)
Exterior	0 (0%)	0 (0%)	4 (2%)	3 (7%)
Other Vehicle	13 (5%)	1 (1%)	3 (2%)	4 (10%)
Roof	73 (31%)	49 (52%)	62 (33%)	10 (24%)
Interior	67 (28%)	21 (22%)	52 (27%)	10 (24%)
Steering	16 (7%)	6 (6%)	20 (11%)	3 (7%)
Wind-shield	1 (0%)	0 (0%)	1 (1%)	3 (7%)
Seat	6 (3%)	0 (0%)	3 (2%)	1 (2%)
Seatbelt	20 (8%)	3 (3%)	8 (4%)	3 (7%)
Airbag	0 (0%)	4 (4%)	3 (2%)	1 (2%)
Other	3 (2%)	0 (0%)	6 (3%)	1 (2%)
Unknown Source	31 (13%)	4 (4%)	10 (5%)	1 (2%)
Total	237 (100%)	95 (100%)	190 (100%)	42 (100%)

The data from Table 24 was further divide to look at vehicle types. Table 25 shows the distribution of injuring contacts/sources for the belted population and Table 26 shows the same information for the unbelted population. At this point it is quite apparent that unbelted occupants for all vehicle classes experienced a higher percentage of injuries from exterior contacts. This is more than explained by the higher percentage of ejected occupants. Of interest for this study are the injuring contact/sources for non-ejected occupants, particularly those that are belted.

For belted occupants, the head was the most frequently injured (AIS 3+) body region. The most common injury source/contact for belted occupants was the roof. Head injuries associated with roof contact were the most frequent injury-source combination for all vehicle types. Of the 564 AIS 3+ injuries to belted occupants, 25% (142) were head-roof interactions. Cars (22%), SUVs (22%), and vans (19%) all experienced a similar percentage of head-roof associated injuries. Pick-up trucks had the highest head-roof injury association at 42%.

Table 26. Unweighted distribution of injuring contact by vehicle type for *unbelted* occupants.

Injury Source	Car	Pick-up	SUV	Van
Ground	295 (33%)	153 (42%)	234 (50%)	95 (61%)
Exterior	32 (4%)	35 (10%)	21 (4%)	9 (6%)
Other Vehicle	23 (3%)	6 (2%)	21 (4%)	0 (0%)
Roof	182 (20%)	64 (17%)	75 (16%)	10 (6%)
Interior	189 (21%)	65 (18%)	53 (11%)	17 (11%)
Steering	74 (8%)	5 (1%)	19 (4%)	5 (3%)
Wind-shield	13 (1%)	5 (1%)	4 (1%)	0 (0%)
Seat	17 (2%)	2 (1%)	1 (0%)	13 (8%)
Seatbelt	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Airbag	2 (0%)	0 (0%)	2 (0%)	0 (0%)
Other	17 (2%)	6 (2%)	5 (1%)	1 (1%)
Unknown Source	59 (8%)	25 (7%)	32 (7%)	5 (3%)
Total	903 (100%)	366 (100%)	467 (100%)	155 (100%)

Data for all injuries and associated sources/contacts are given in the Appendix for all vehicle types. The data is also provided for belted and unbelted occupants.

Many of the belted occupant's injuries were also attributed to impact with the vehicle interior. Most vehicles contained within this data set do not yet meet the current FMVSS 201 standard for interior impact protection. It may be useful to analyze these interior contact injuries and assess how the effectiveness of the 201 standard may have helped reduce the risk of injury.

One interesting finding was that unbelted occupants, that were not ejected, showed similar trends to the belted occupants. Roof associated head injury was the most frequent injury. It was 3.1 times as likely to occur as any other injury. It was also 1.7 times more likely to occur when compared to non-ejected belted occupants. Again, this emphasizes the importance of belt usage.

The final aspect of this study was to investigate the variable of maximum roof deformation as it relates to the head-roof associated injuries. Data for all injuries was divided by the maximum roof deformation metric. This data was limited to belted occupants that were not ejected, resulting in 446 total AIS 3+ injuries. Similarly, the 142 head injuries associated with roof contact were divided into the deformation categories (Table 27). From this table it can be seen that 57% of all injuries occur at roof deformations greater than the allowable limit of the FMVSS 216 standard. For head injuries associated with the roof, 81% occur when the FMVSS 216 deformation limit is exceeded. Again, it must be noted that the loading in these cases is dynamic and has not been controlled for or correlated to the FMVSS 216 specifications.

Table 27. Unweighted distribution of injuries for belted, non-ejected occupants by maximum roof deformation.

Max Roof Deformation	All AIS 3+ Injuries		Head-Roof AIS 3+ Injuries	
	Count	%	Count	%
0 cm	117	26%	12	8%
1 – 7 cm	21	5%	2	1%
8 – 14 cm	54	12%	12	8%
15 – 29 cm	81	18%	29	20%
30 – 45 cm	102	23%	53	37%
46 – 60 cm	33	7%	20	14%
≥ 61 cm	38	9%	14	10%
Total	446	100%	142	100%

Data for all injuries can also be used as the normalizing factor for the effects of roof deformation on injury. For each level of deformation it is possible to calculate the rate of head-roof injuries to all AIS 3+ injuries. This data is given in Table 28.

Table 28. Rate of head-roof associated injury by maximum roof deformation.

Max Roof Deformation	All AIS 3+ Injuries	Head-Roof AIS 3+ Injuries	Rate of Head-Roof Injury
	Count	Count	%
0 cm	117	12	10.3%
1 – 7 cm	21	2	9.5%
8 – 14 cm	54	12	22.2%
15 – 29 cm	81	29	35.8%
30 – 45 cm	102	53	52.0%
46 – 60 cm	33	20	60.6%
≥ 61 cm	38	14	36.8%
Total	446	142	31.8%

Table 28 indicates that head-roof injury tends to increase in frequency relative to other injuries as roof deformation increases. The only exception is beyond 61 cm (24 in.). This does not indicate a causal effect for two primary reasons: 1) it does not take into account the kinematics of the vehicle or occupant during the crash; and 2) it is not a biomechanical metric related to injury risk. The frequency of head-roof injuries along with the relationship between roof deformation and head injury does warrant further investigation into the role that roof deformation may play in these injuries. This would include a further understanding of the type of deformation, extent of deformation, and rate of deformation.

CONCLUSIONS

An investigation of the circumstances surrounding vehicle rollover has been completed using the NASS CDS database for the years 1997-2000. Rollover events were examined by frequency of occurrence, severity by number of quarter turns, direction of roll, roll initiation source, roll location relative to the roadway, and by extent of roof intrusion. Occupants were examined by distribution of MAIS, safety belt usage, extent of ejection, and proximity to the roll direction. Occupant injuries have been examined by safety belt usage, body region distribution, injuring contact/source, and relationship to intrusion and roof deformation. Most data has been distributed by vehicle type.

The weighted NASS data indicated that:

- Cars account for 44.4% of rollover events with AIS 3+ injuries, pick-ups 26.3%, SUVs 25.0%, and vans 4.3%. SUVs comprise 9% of the registered vehicle population and account for 25% of the rollover cases.
- There was an approximate 50-50 split in roll direction and the injured occupant was on the near-side of the roll 49% of the time, the far-side 48%, and 3% in center seating positions. Injuries did not necessarily correlate with proximity to roll direction.
- The ground initiated 57% of rollovers for all vehicles. Fixed objects were the second most frequent at 13%. LTVs experience a higher percentage of ground-induced rollovers compared to cars (68% vs. 44%), while cars have a higher percentage initiated by fixed object contacts (24% vs. 5%).
- Weighted and unweighted NASS CDS distributions were very similar with regard to number of quarter turns. Of the cases, 83% of the crashes involved 2 or more quarter turns, and 45% of vehicles that experience only 1 quarter turn, also experience roof deformation. For cases with only 1 quarter turn and roof deformation, the deformation was typically associated with a secondary planar impact that impeded the roll.

The unweighted NASS data provided the following insights:

- For the population of vehicles in rollover crashes, 53% exceeded 15cm of deformation (FMVSS 216 regulates to 12.7cm). For vehicles that experienced only 1 quarter turn, 31% exceeded 15cm of deformation, while 58% of vehicles that experienced 2 or more quarter turns exceeded that amount.
- Head injuries (including face and brain) account for 45% of all AIS 3+ injuries. Chest injuries are the second most frequent at 22%. Neck injury (often a focus in rollover testing) only accounted for 5% of AIS 3+ injuries. This was fewer injuries than the lower extremities, upper extremities, and the abdomen.
- Head injuries associated with roof contact were the most frequent injury-source combination for all vehicle types.
- For all AIS 3+ injuries, 57% occur at roof deformations greater than the allowable limit of the FMVSS 216 standard. For head injuries associated with the roof, 81% occur when this deformation limit is exceeded.
- As roof deformation increases, head-to-roof associated injury tends to increase in frequency relative to other injuries.
- The highest opportunity area for mitigating injuries to *belted* occupants was to the head and neck, which accounted for 45% of all AIS 3+ injuries. This was similar for *unbelted* occupants at 52% of all AIS 3+ injuries.
- The highest opportunity area for mitigating injuries by contact/source for *belted* occupants is associated with the roof and interior surfaces, which accounts for 60% of all AIS 3+ contacts. For *unbelted* occupants, the opportunity area is 49% for contacts exterior to the vehicle, and 35% for the roof and interior surfaces.
- The opportunity area with regard to ejection mitigation is 49% for *unbelted* occupants (66% of unbelted injuries) and 11% for *belted* occupants (18% of belted injuries).

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APPENDIX

Table A-1. Injury distribution by body region and injury source for *belted non-ejected* occupants in *passenger cars*. Highest frequencies have been highlighted.

Body Region	Injury Source	AIS 3		AIS 4		AIS 5		AIS 6		Total	
		#	%	#	%	#	%	#	%	#	%
HEAD	Roof	23	15.23%	22	40.74%	7	28.00%	1	14.29%	53	22.36%
	Interior	4	2.65%	4	7.41%	1	4.00%	1	14.29%	10	4.22%
	Other Vehicle	6	3.97%	0	0.00%	0	0.00%	0	0.00%	6	2.53%
	Ground	1	0.66%	2	3.70%	2	8.00%	0	0.00%	5	2.11%
	Unknown Source	2	1.32%	0	0.00%	1	4.00%	1	14.29%	4	1.69%
	Windshield	0	0.00%	1	1.85%	0	0.00%	0	0.00%	1	0.42%
	Other Occupants	0	0.00%	1	1.85%	0	0.00%	0	0.00%	1	0.42%
	Seatbelt	0	0.00%	1	1.85%	0	0.00%	0	0.00%	1	0.42%
	Other Noncontact	0	0.00%	0	0.00%	1	4.00%	0	0.00%	1	0.42%
CHEST	Interior	14	9.27%	10	18.52%	4	16.00%	2	28.57%	30	12.66%
	Seatbelt	9	5.96%	4	7.41%	1	4.00%	0	0.00%	14	5.91%
	Steering	8	5.30%	1	1.85%	1	4.00%	0	0.00%	10	4.22%
	Unknown Source	4	2.65%	1	1.85%	1	4.00%	0	0.00%	6	2.53%
	Other Vehicle	1	0.66%	1	1.85%	0	0.00%	1	14.29%	3	1.27%
	Roof	2	1.32%	0	0.00%	0	0.00%	0	0.00%	2	0.84%
	Seat	1	0.66%	0	0.00%	0	0.00%	0	0.00%	1	0.42%
ARM	Interior	9	5.96%	0	0.00%	0	0.00%	0	0.00%	9	3.80%
	Roof	5	3.31%	0	0.00%	0	0.00%	0	0.00%	5	2.11%
	Unknown Source	3	1.99%	0	0.00%	0	0.00%	0	0.00%	3	1.27%
	Steering	3	1.99%	0	0.00%	0	0.00%	0	0.00%	3	1.27%
	Seat	3	1.99%	0	0.00%	0	0.00%	0	0.00%	3	1.27%
	Other Vehicle	2	1.32%	0	0.00%	0	0.00%	0	0.00%	2	0.84%
	Ground	2	1.32%	0	0.00%	0	0.00%	0	0.00%	2	0.84%
LEG/LOWER	Interior	8	5.30%	0	0.00%	0	0.00%	0	0.00%	8	3.38%
	Unknown Source	6	3.97%	0	0.00%	0	0.00%	0	0.00%	6	2.53%
	Steering	3	1.99%	0	0.00%	0	0.00%	0	0.00%	3	1.27%
	Floor	1	0.66%	0	0.00%	0	0.00%	0	0.00%	1	0.42%
	Seat	1	0.66%	0	0.00%	0	0.00%	0	0.00%	1	0.42%
NECK	Roof	12	7.95%	0	0.00%	1	4.00%	0	0.00%	13	5.49%
	Unknown Source	1	0.66%	0	0.00%	0	0.00%	1	14.29%	2	0.84%
	Other Vehicle	1	0.66%	0	0.00%	0	0.00%	0	0.00%	1	0.42%
	Seat	1	0.66%	0	0.00%	0	0.00%	0	0.00%	1	0.42%
ABDOMEN	Unknown Source	2	1.32%	4	7.41%	1	4.00%	0	0.00%	7	2.95%
	Interior	2	1.32%	2	3.70%	1	4.00%	0	0.00%	5	2.11%
	Seatbelt	2	1.32%	0	0.00%	2	8.00%	0	0.00%	4	1.69%
	Other Vehicle	1	0.66%	0	0.00%	0	0.00%	0	0.00%	1	0.42%
PELVIC/HIP	Interior	4	2.65%	0	0.00%	0	0.00%	0	0.00%	4	1.69%
	Unknown Source	2	1.32%	0	0.00%	0	0.00%	0	0.00%	2	0.84%
	Seatbelt	1	0.66%	0	0.00%	0	0.00%	0	0.00%	1	0.42%
BACK	Unknown Source	1	0.66%	0	0.00%	0	0.00%	0	0.00%	1	0.42%
	Interior	0	0.00%	0	0.00%	1	4.00%	0	0.00%	1	0.42%
Total		151	100%	54	100%	25	100%	7	100%	237	100%

Table A-2. Injury distribution by body region and injury source for *unbelted non-ejected* occupants in *passenger cars*. Highest frequencies have been highlighted.

Body Region	Injury Source	AIS 3		AIS 4		AIS 5		AIS 6		Total	
		#	%	#	%	#	%	#	%	#	%
HEAD	Roof	44	19.38%	21	30.00%	7	23.33%	2	22.22%	74	22.02%
	Interior	19	8.37%	11	15.71%	7	23.33%	0	0.00%	37	11.01%
	Unknown Source	4	1.76%	5	7.14%	5	16.67%	0	0.00%	14	4.17%
	Windshield	4	1.76%	2	2.86%	3	10.00%	0	0.00%	9	2.68%
	Ground	0	0.00%	4	5.71%	0	0.00%	0	0.00%	4	1.19%
	Other Vehicle	0	0.00%	1	1.43%	0	0.00%	1	11.11%	2	0.60%
	Steering	0	0.00%	1	1.43%	0	0.00%	0	0.00%	1	0.30%
CHEST	Steering	16	7.05%	11	15.71%	3	10.00%	2	22.22%	32	9.52%
	Interior	11	4.85%	3	4.29%	0	0.00%	0	0.00%	14	4.17%
	Roof	4	1.76%	1	1.43%	2	6.67%	1	11.11%	8	2.38%
	Seat	5	2.20%	1	1.43%	0	0.00%	0	0.00%	6	1.79%
	Unknown Source	2	0.88%	2	2.86%	0	0.00%	0	0.00%	4	1.19%
	Other Occupants	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Other Vehicle	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
	Ground	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
	Other Noncontact	0	0.00%	0	0.00%	0	0.00%	1	11.11%	1	0.30%
	Seatbelt	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
	Airbag	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
LEG/LOWER	Interior	26	11.45%	0	0.00%	0	0.00%	0	0.00%	26	7.74%
	Unknown Source	3	1.32%	0	0.00%	0	0.00%	0	0.00%	3	0.89%
	Floor	3	1.32%	0	0.00%	0	0.00%	0	0.00%	3	0.89%
	Steering	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Seat	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Ground	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
NECK	Roof	12	5.29%	0	0.00%	0	0.00%	0	0.00%	12	3.57%
	Windshield	3	1.32%	1	1.43%	0	0.00%	0	0.00%	4	1.19%
	Unknown Source	4	1.76%	0	0.00%	0	0.00%	0	0.00%	4	1.19%
	Ground	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Other Vehicle	0	0.00%	0	0.00%	0	0.00%	1	11.11%	1	0.30%
	Steering	0	0.00%	0	0.00%	1	3.33%	0	0.00%	1	0.30%
PELVIC/HIP	Interior	12	5.29%	0	0.00%	0	0.00%	0	0.00%	12	3.57%
	Steering	6	2.64%	0	0.00%	0	0.00%	0	0.00%	6	1.79%
	Unknown Source	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Seat	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Ground	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
ARM	Interior	8	3.52%	0	0.00%	0	0.00%	0	0.00%	8	2.38%
	Roof	4	1.76%	0	0.00%	0	0.00%	0	0.00%	4	1.19%
	Steering	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Airbag	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
ABDOMEN	Steering	4	1.76%	1	1.43%	0	0.00%	0	0.00%	5	1.49%
	Interior	3	1.32%	1	1.43%	0	0.00%	0	0.00%	4	1.19%
	Roof	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Unknown Source	0	0.00%	1	1.43%	0	0.00%	0	0.00%	1	0.30%
	Other Vehicle	0	0.00%	1	1.43%	0	0.00%	0	0.00%	1	0.30%
	Ground	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
BACK	Roof	2	0.88%	1	1.43%	2	6.67%	0	0.00%	5	1.49%
	Ground	2	0.88%	0	0.00%	0	0.00%	0	0.00%	2	0.60%
	Steering	0	0.00%	1	1.43%	0	0.00%	0	0.00%	1	0.30%
	Other Noncontact	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
	Seat	1	0.44%	0	0.00%	0	0.00%	0	0.00%	1	0.30%
INJURED/UNK	Other	0	0.00%	0	0.00%	0	0.00%	1	11.11%	1	0.30%
Total		227	100%	70	100%	30	100%	9	100%	336	100%

Table A-3. Injury distribution by body region and injury source for *belted non-ejected* occupants in *pick-up trucks*. Highest frequencies have been highlighted.

Body Region	Injury Source	AIS 3		AIS 4		AIS 5		AIS 6		Total	
		#	%	#	%	#	%	#	%	#	%
HEAD	Roof	19	31.15%	11	61.11%	10	71.43%	0	0.00%	40	42.11%
	Ground	1	1.64%	0	0.00%	0	0.00%	1	50.00%	2	2.11%
CHEST	Interior	3	4.92%	2	11.11%	0	0.00%	0	0.00%	5	5.26%
	Steering	3	4.92%	1	5.56%	0	0.00%	0	0.00%	4	4.21%
	Seatbelt	1	1.64%	2	11.11%	0	0.00%	0	0.00%	3	3.16%
	Airbag	2	3.28%	0	0.00%	0	0.00%	0	0.00%	2	2.11%
	Unknown Source	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.05%
	Roof	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.05%
ARM	Interior	9	14.75%	0	0.00%	0	0.00%	0	0.00%	9	9.47%
	Ground	5	8.20%	0	0.00%	0	0.00%	0	0.00%	5	5.26%
	Airbag	2	3.28%	0	0.00%	0	0.00%	0	0.00%	2	2.11%
NECK	Roof	4	6.56%	1	5.56%	2	14.29%	1	50.00%	8	8.42%
	Unknown Source	0	0.00%	0	0.00%	1	7.14%	0	0.00%	1	1.05%
LEG/LOWER	Interior	4	6.56%	0	0.00%	0	0.00%	0	0.00%	4	4.21%
	Unknown Source	2	3.28%	0	0.00%	0	0.00%	0	0.00%	2	2.11%
	Steering	2	3.28%	0	0.00%	0	0.00%	0	0.00%	2	2.11%
	Other Vehicle	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.05%
ABDOMEN	Interior	1	1.64%	1	5.56%	0	0.00%	0	0.00%	2	2.11%
BACK	Interior	0	0.00%	0	0.00%	1	7.14%	0	0.00%	1	1.05%
Total		61	100%	18	100%	14	100%	2	100%	95	100%

Table A-4. Injury distribution by body region and injury source for *unbelted non-ejected* occupants in *pick-up trucks*. Highest frequencies have been highlighted.

Body Region	Injury Source	AIS 3		AIS 4		AIS 5		AIS 6		Total	
		#	%	#	%	#	%	#	%	#	%
HEAD	Roof	5	12.20%	5	41.67%	4	40.00%	1	50.00%	15	23.08%
	Interior	3	7.32%	1	8.33%	1	10.00%	0	0.00%	5	7.69%
	Ground	1	2.44%	0	0.00%	1	10.00%	0	0.00%	2	3.08%
	Exterior	0	0.00%	0	0.00%	0	0.00%	1	50.00%	1	1.54%
CHEST	Interior	4	9.76%	1	8.33%	0	0.00%	0	0.00%	5	7.69%
	Unknown Source	3	7.32%	0	0.00%	0	0.00%	0	0.00%	3	4.62%
	Other Occupants	0	0.00%	3	25.00%	0	0.00%	0	0.00%	3	4.62%
	Steering	0	0.00%	0	0.00%	2	20.00%	0	0.00%	2	3.08%
	Roof	2	4.88%	0	0.00%	0	0.00%	0	0.00%	2	3.08%
	Ground	0	0.00%	1	8.33%	0	0.00%	0	0.00%	1	1.54%
	Seat	1	2.44%	0	0.00%	0	0.00%	0	0.00%	1	1.54%
LEG/LOWER	Interior	7	17.07%	0	0.00%	0	0.00%	0	0.00%	7	10.77%
	Unknown Source	2	4.88%	0	0.00%	0	0.00%	0	0.00%	2	3.08%
NECK	Roof	3	7.32%	0	0.00%	1	10.00%	0	0.00%	4	6.15%
	Unknown Source	2	4.88%	0	0.00%	0	0.00%	0	0.00%	2	3.08%
ARM	Interior	3	7.32%	0	0.00%	0	0.00%	0	0.00%	3	4.62%
	Other Vehicle	1	2.44%	0	0.00%	0	0.00%	0	0.00%	1	1.54%
	Exterior	1	2.44%	0	0.00%	0	0.00%	0	0.00%	1	1.54%
ABDOMEN	Other Occupants	1	2.44%	0	0.00%	1	10.00%	0	0.00%	2	3.08%
	Seat	0	0.00%	1	8.33%	0	0.00%	0	0.00%	1	1.54%
	Roof	1	2.44%	0	0.00%	0	0.00%	0	0.00%	1	1.54%
BACK	Other Occupants	1	2.44%	0	0.00%	0	0.00%	0	0.00%	1	1.54%
Total		41	100%	12	100%	10	100%	2	100%	65	100%

Table A-5. Injury distribution by body region and injury source for *belted non-ejected* occupants in *sport utility vehicles (SUVs)*. Highest frequencies have been highlighted.

Body Region	Injury Source	AIS 3		AIS 4		AIS 5		AIS 6		Total	
		#	%	#	%	#	%	#	%	#	%
HEAD	Roof	23	17.69%	11	30.56%	7	33.33%	0	0.00%	41	21.58%
	Steering	4	3.08%	1	2.78%	2	9.52%	0	0.00%	7	3.68%
	Ground	3	2.31%	4	11.11%	0	0.00%	0	0.00%	7	3.68%
	Unknown Source	4	3.08%	1	2.78%	0	0.00%	0	0.00%	5	2.63%
	Airbag	2	1.54%	0	0.00%	1	4.76%	0	0.00%	3	1.58%
	Interior	1	0.77%	2	5.56%	0	0.00%	0	0.00%	3	1.58%
	Windshield	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
	Seat	0	0.00%	0	0.00%	1	4.76%	0	0.00%	1	0.53%
CHEST	Interior	7	5.38%	6	16.67%	3	14.29%	0	0.00%	16	8.42%
	Steering	4	3.08%	2	5.56%	0	0.00%	1	33.33%	7	3.68%
	Roof	2	1.54%	1	2.78%	2	9.52%	1	33.33%	6	3.16%
	Seatbelt	4	3.08%	0	0.00%	0	0.00%	0	0.00%	4	2.11%
	Exterior	1	0.77%	1	2.78%	0	0.00%	0	0.00%	2	1.05%
	Unknown Source	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
	Other	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
	Ground	0	0.00%	0	0.00%	1	4.76%	0	0.00%	1	0.53%
ARM	Interior	12	9.23%	0	0.00%	0	0.00%	0	0.00%	12	6.32%
	Ground	9	6.92%	0	0.00%	0	0.00%	0	0.00%	9	4.74%
	Roof	5	3.85%	0	0.00%	0	0.00%	0	0.00%	5	2.63%
	Unknown Source	3	2.31%	0	0.00%	0	0.00%	0	0.00%	3	1.58%
	Other Vehicle	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
	Other Occupants	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
LEG/LOWER	Interior	14	10.77%	0	0.00%	0	0.00%	0	0.00%	14	7.37%
	Other Vehicle	2	1.54%	0	0.00%	0	0.00%	0	0.00%	2	1.05%
	Floor	2	1.54%	0	0.00%	0	0.00%	0	0.00%	2	1.05%
	Steering	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
NECK	Roof	8	6.15%	0	0.00%	0	0.00%	0	0.00%	8	4.21%
	Interior	4	3.08%	0	0.00%	0	0.00%	0	0.00%	4	2.11%
	Seat	2	1.54%	0	0.00%	0	0.00%	0	0.00%	2	1.05%
	Other Noncontact	1	0.77%	1	2.78%	0	0.00%	0	0.00%	2	1.05%
	Unknown Source	0	0.00%	0	0.00%	1	4.76%	0	0.00%	1	0.53%
	Ground	0	0.00%	1	2.78%	0	0.00%	0	0.00%	1	0.53%
ABDOMEN	Steering	0	0.00%	0	0.00%	3	14.29%	0	0.00%	3	1.58%
	Seatbelt	1	0.77%	2	5.56%	0	0.00%	0	0.00%	3	1.58%
	Exterior	0	0.00%	2	5.56%	0	0.00%	0	0.00%	2	1.05%
	Roof	1	0.77%	0	0.00%	0	0.00%	1	33.33%	2	1.05%
	Interior	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
PELVIC/HIP	Steering	2	1.54%	0	0.00%	0	0.00%	0	0.00%	2	1.05%
	Interior	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
BACK	Seatbelt	1	0.77%	0	0.00%	0	0.00%	0	0.00%	1	0.53%
	Interior	0	0.00%	1	2.78%	0	0.00%	0	0.00%	1	0.53%
Total		130	100%	36	100%	21	100%	3	100%	190	100%

Table A-6. Injury distribution by body region and injury source for *unbelted non-ejected* occupants in *sport utility vehicles (SUVs)*. Highest frequencies have been highlighted.

Body Region	Injury Source	AIS 3		AIS 4		AIS 5		AIS 6		Total	
		#	%	#	%	#	%	#	%	#	%
HEAD	Roof	15	24.59%	4	26.67%	6	35.29%	0	0.00%	25	26.88%
	Other Vehicle	5	8.20%	2	13.33%	2	11.76%	0	0.00%	9	9.68%
	Windshield	2	3.28%	1	6.67%	1	5.88%	0	0.00%	4	4.30%
	Interior	1	1.64%	1	6.67%	2	11.76%	0	0.00%	4	4.30%
	Steering	1	1.64%	1	6.67%	0	0.00%	0	0.00%	2	2.15%
	Other Noncontact	0	0.00%	0	0.00%	1	5.88%	0	0.00%	1	1.08%
	Ground	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
	Unknown Source	0	0.00%	0	0.00%	1	5.88%	0	0.00%	1	1.08%
CHEST	Interior	4	6.56%	3	20.00%	2	11.76%	0	0.00%	9	9.68%
	Steering	4	6.56%	2	13.33%	0	0.00%	0	0.00%	6	6.45%
	Roof	2	3.28%	0	0.00%	0	0.00%	0	0.00%	2	2.15%
	Unknown Source	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
	Other Noncontact	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
	Ground	0	0.00%	1	6.67%	0	0.00%	0	0.00%	1	1.08%
ARM	Interior	4	6.56%	0	0.00%	0	0.00%	0	0.00%	4	4.30%
	Airbag	2	3.28%	0	0.00%	0	0.00%	0	0.00%	2	2.15%
	Unknown Source	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
	Roof	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
	Steering	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
LEG/LOWER	Interior	5	8.20%	0	0.00%	0	0.00%	0	0.00%	5	5.38%
	Steering	2	3.28%	0	0.00%	0	0.00%	0	0.00%	2	2.15%
PELVIC/HIP	Steering	3	4.92%	0	0.00%	0	0.00%	0	0.00%	3	3.23%
	Interior	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
ABDOMEN	Unknown Source	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
	Ground	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
	Interior	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
INJURED/UNK	Other	0	0.00%	0	0.00%	2	11.76%	0	0.00%	2	2.15%
NECK	Ground	1	1.64%	0	0.00%	0	0.00%	0	0.00%	1	1.08%
Total		61	100%	15	100%	17	100%	0	0%	93	100%

Table A-7. Injury distribution by body region and injury source for *belted non-ejected* occupants in *passenger vans*. Highest frequencies have been highlighted.

Body Region	Injury Source	AIS 3		AIS 4		AIS 5		AIS 6		Total	
		#	%	#	%	#	%	#	%	#	%
HEAD	Roof	4	13.33%	2	22.22%	1	50.00%	1	100.00%	8	19.05%
	Other Vehicle	1	3.33%	3	33.33%	0	0.00%	0	0.00%	4	9.52%
	Windshield	3	10.00%	0	0.00%	0	0.00%	0	0.00%	3	7.14%
	Steering	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
CHEST	Interior	2	6.67%	1	11.11%	0	0.00%	0	0.00%	3	7.14%
	Exterior	1	3.33%	1	11.11%	1	50.00%	0	0.00%	3	7.14%
	Steering	0	0.00%	1	11.11%	0	0.00%	0	0.00%	1	2.38%
	Seatbelt	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
LEG/LOWER	Interior	3	10.00%	0	0.00%	0	0.00%	0	0.00%	3	7.14%
	Ground	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
ABDOMEN	Seatbelt	2	6.67%	0	0.00%	0	0.00%	0	0.00%	2	4.76%
	Steering	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
	Interior	0	0.00%	1	11.11%	0	0.00%	0	0.00%	1	2.38%
ARM	Interior	3	10.00%	0	0.00%	0	0.00%	0	0.00%	3	7.14%
	Ground	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
BACK	Unknown Source	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
	Airbag	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
	Seat	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
NECK	Roof	2	6.67%	0	0.00%	0	0.00%	0	0.00%	2	4.76%
PELVIC/HIP	Floor	1	3.33%	0	0.00%	0	0.00%	0	0.00%	1	2.38%
Total		30	100%	9	100%	2	100%	1	100%	42	100%